

# Aviation Climate Impact: Scientific Status

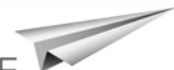
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100 JAHRE  
Luft- und Raumfahrtforschung  
in Deutschland



# Understanding of Aviation climate impact - History

1971/72: Johnston, Crutzen:  $\text{NO}_x$  from super-sonic transport causes stratospheric  $\text{O}_3$  depletion

1977: Hidlago and Crutzen:  $\text{NO}_x$  from subsonic aviation causes  $\text{O}_3$  formation in troposphere and lower stratosphere

1990: Liou: Aviation causes observable increases in contrail cirrus

1996: Fuglestvedt:  $\text{NO}_x$  not only increases  $\text{O}_3$ , it also reduces  $\text{CH}_4$

1999: IPCC: Non- $\text{CO}_2$  effects in 1992 cause 3.5 times as much radiative forcing as past aviation  $\text{CO}_2$  emissions

2001: ACARE: technology development goal with 50 %  $\text{CO}_2$  reduction and 80 %  $\text{NO}_x$  reduction by 2020; no targets for soot, contrails

2007: IPCC: in order to avoid a dangerous warming by mid 2050,  $\text{CO}_2$  emission have to be reduced by >60 % compared to 2000

(2001-)2009:  $\text{NO}_x$  causes short-lived  $\text{O}_3$ , but reduces  $\text{CH}_4$  and  $\text{O}_3$  in the long-term, hence aviation  $\text{NO}_x$  may eventually become cooling

## Aviation is second after road in climate impact of traffic

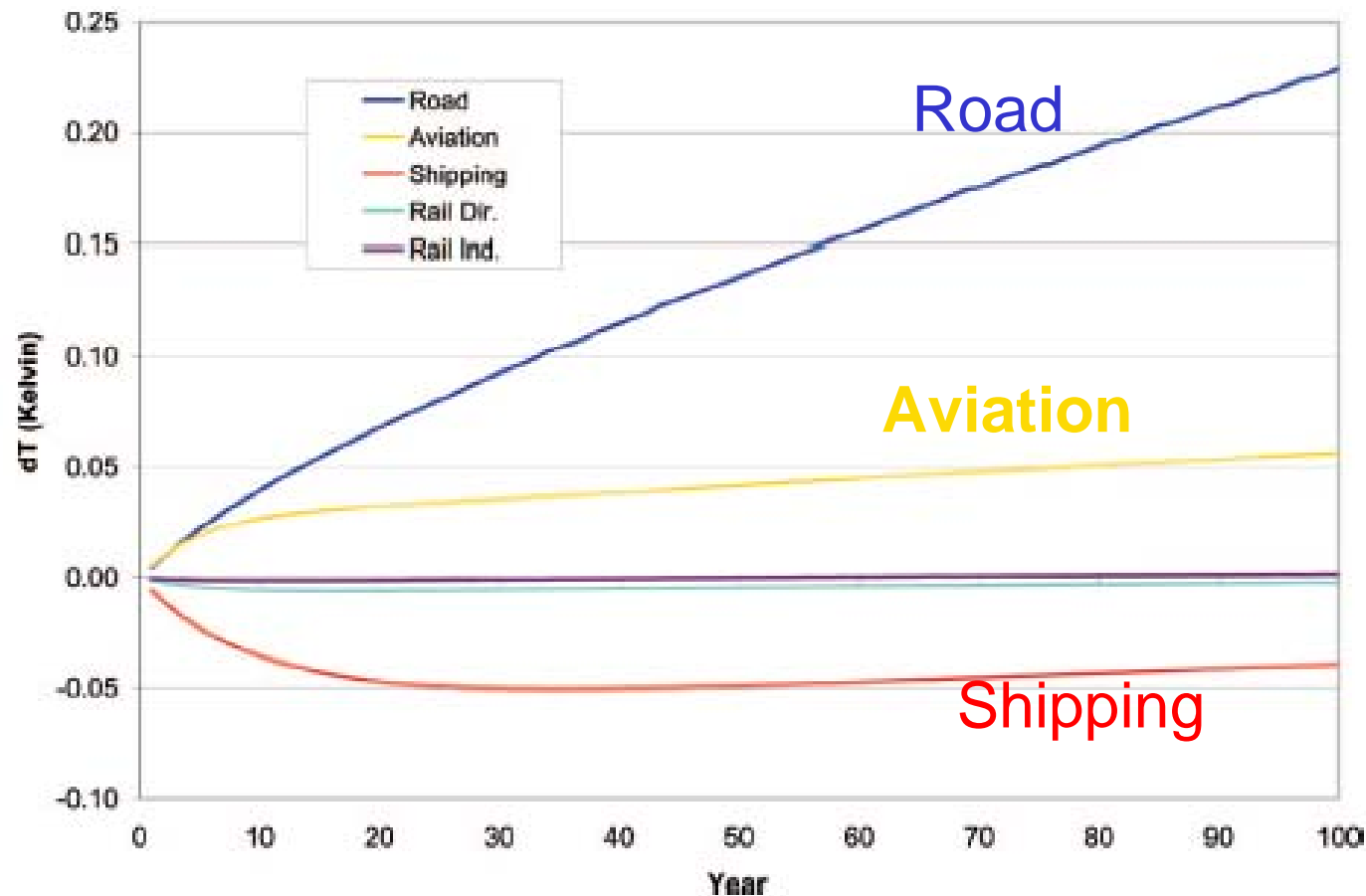
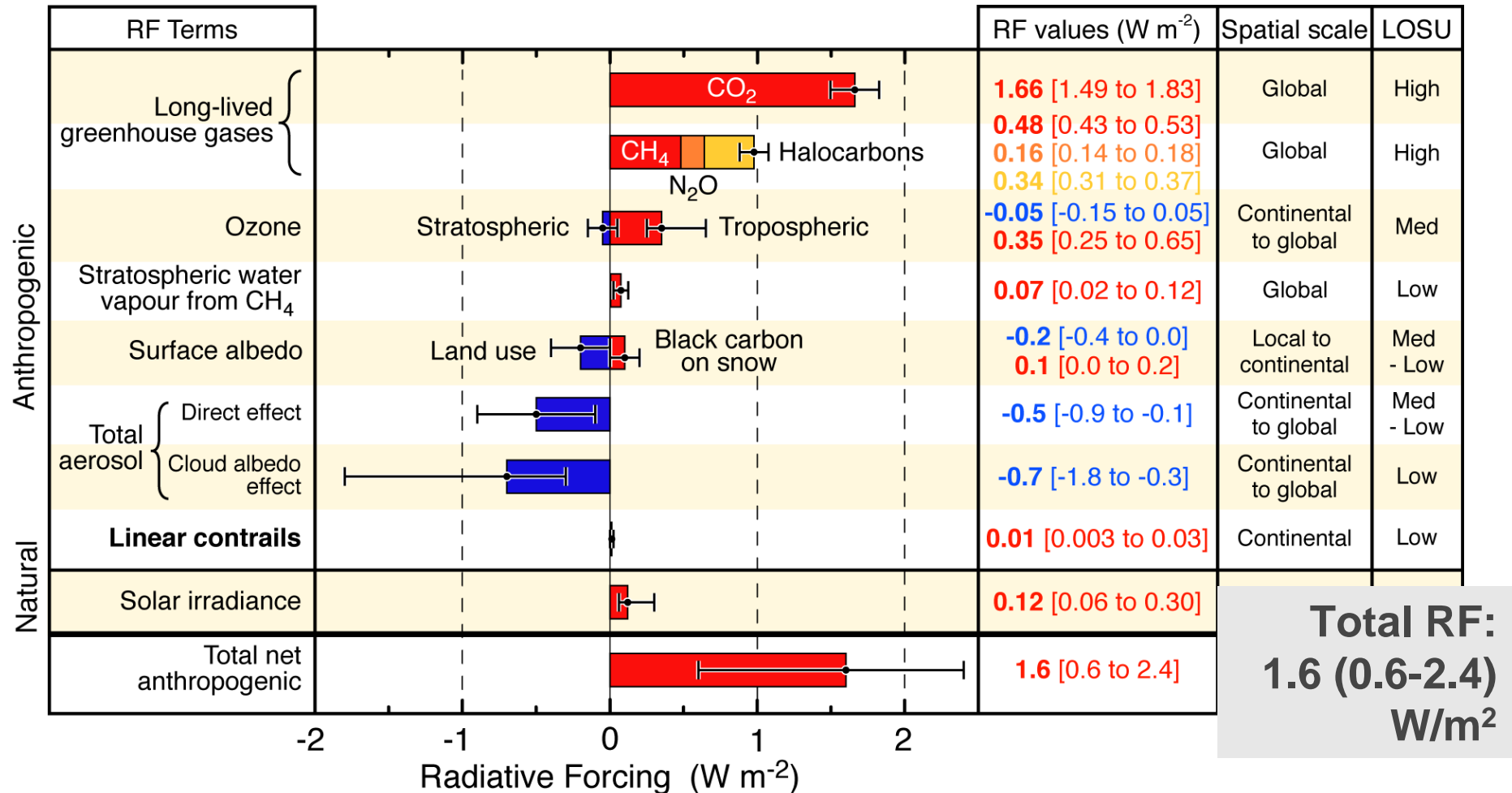


Fig. 4. Future temperature change (Kelvin) due to transportation with constant 2000 emissions.

(Berntsen & Fuglestvedt, PNAS, 2008)

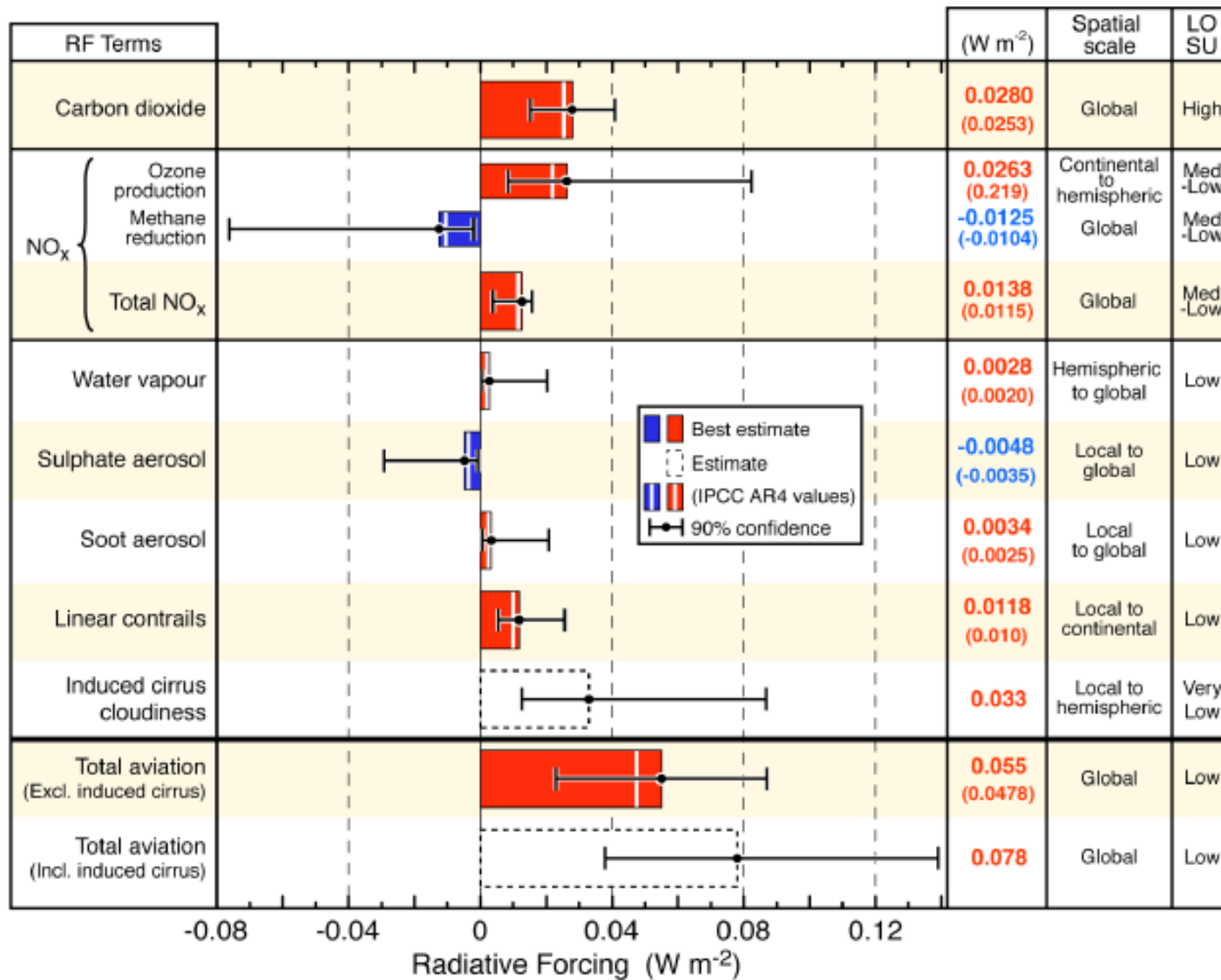
# For Reference: Global Radiative Forcing 1750-2005, from all sources

Global Radiative Forcing Components in 2005



(IPCC, 2007; Lee et al., 2009a)

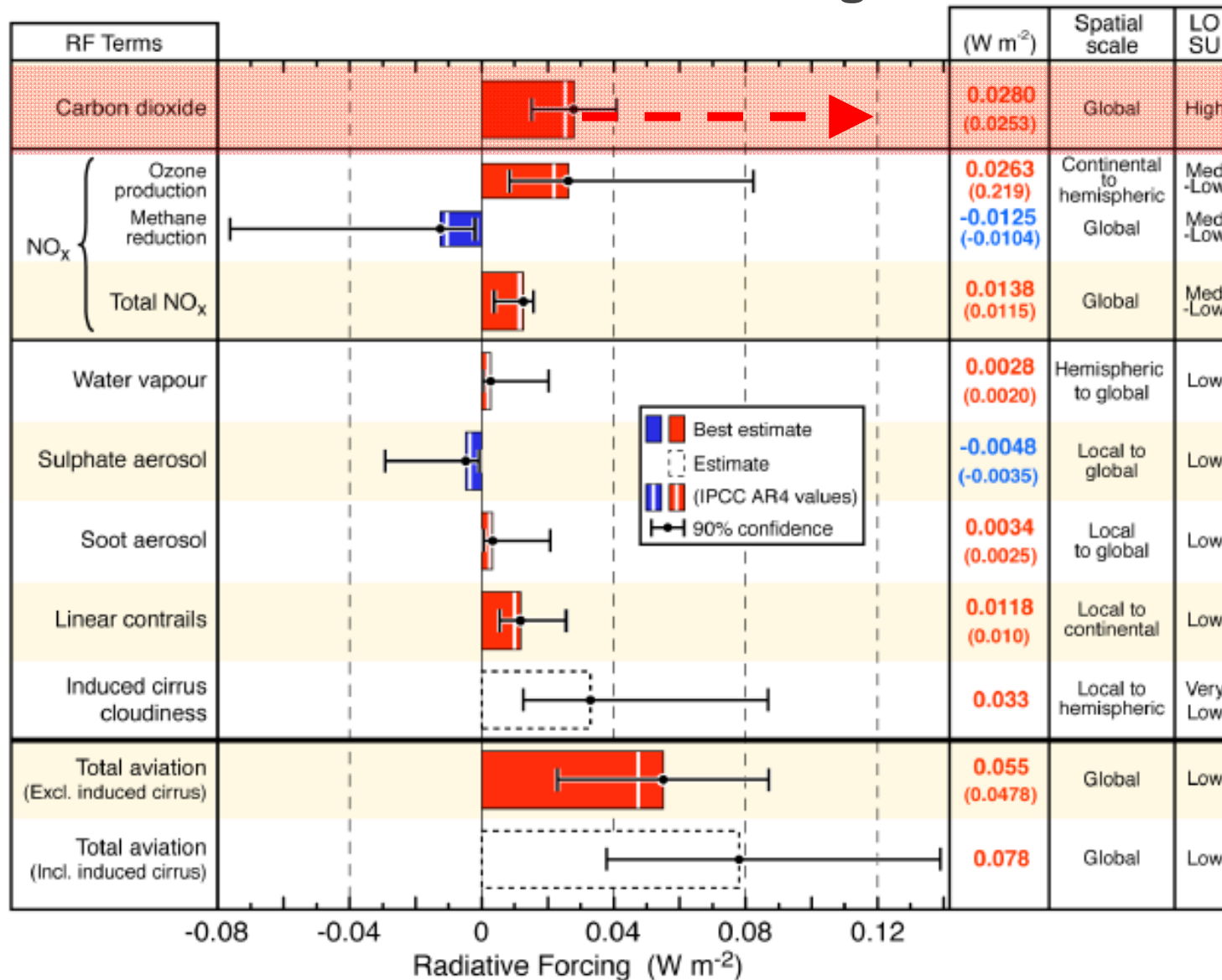
# Global Radiative Forcing 1750-2005, from aviation



**Aviation RF contribution**  
**0.04-0.14 W/m<sup>2</sup>**  
**or 3 – 8 % of total**

(Lee et al., 2009a)

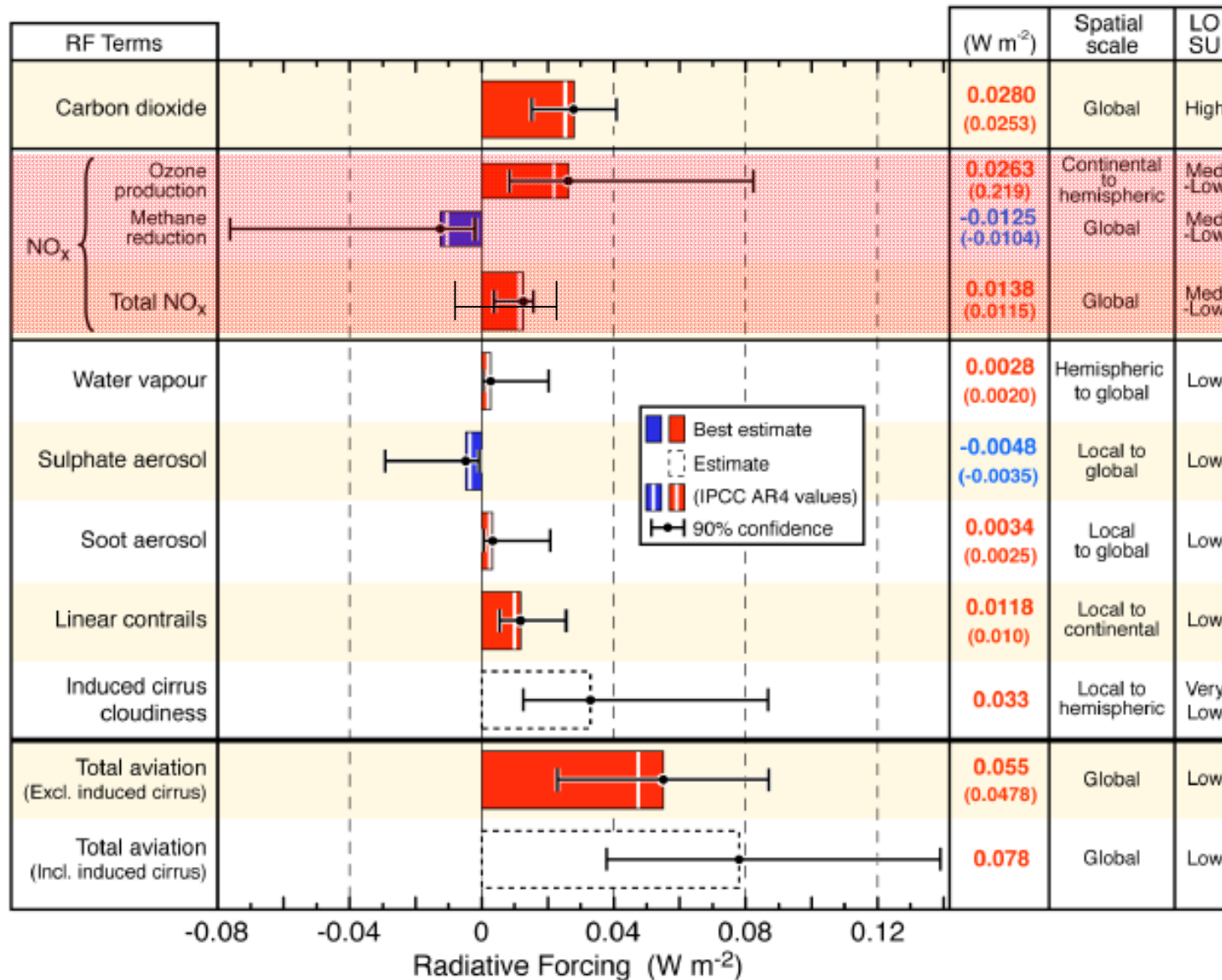
# Aviation Radiative Forcing: Main Contributions



RF from aviation CO<sub>2</sub> forms presently about 1/3 of the total aviation RF.

Because of large lifetime, the CO<sub>2</sub>-RF keeps growing even for constant emissions

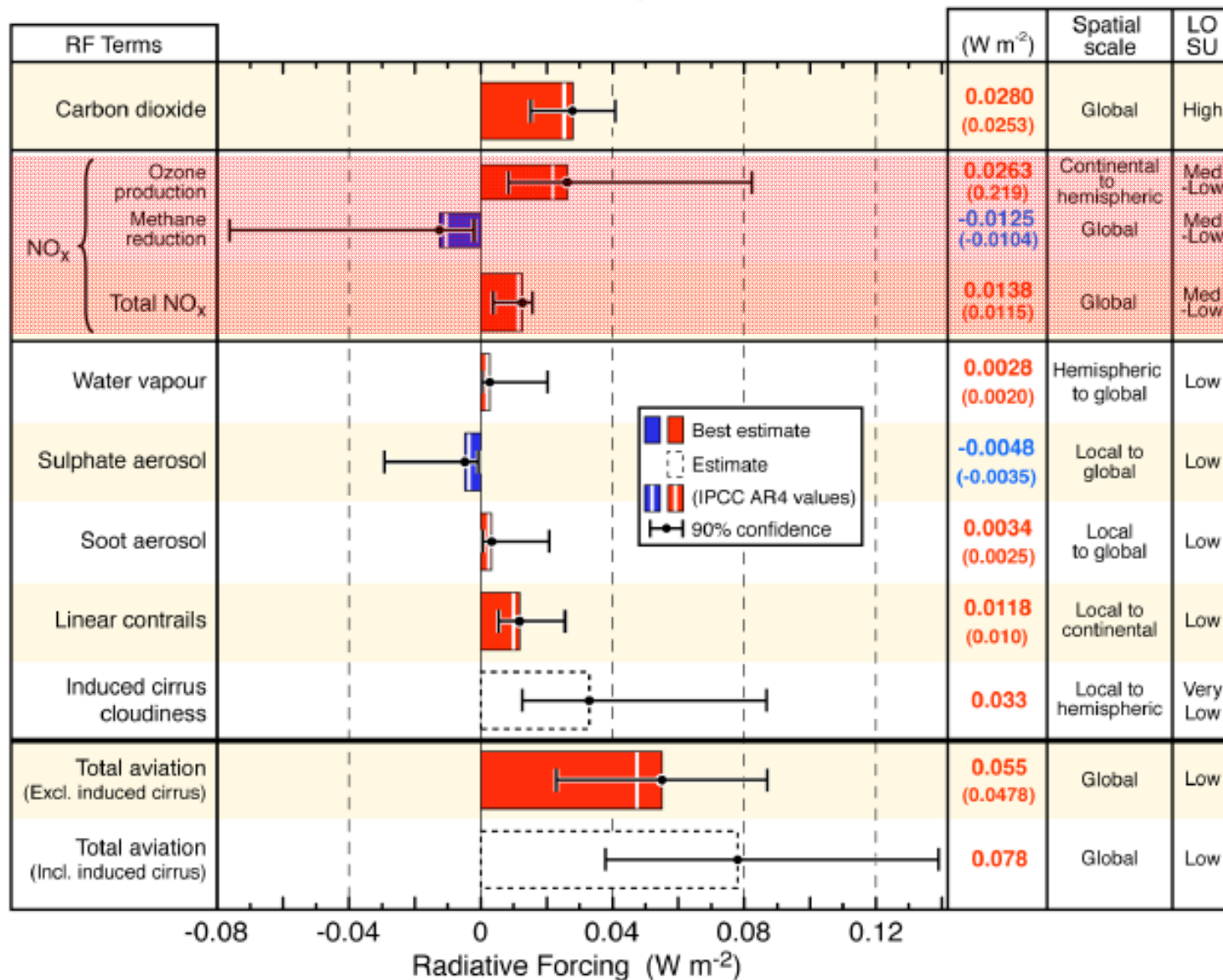
# Aviation Radiative Forcing: Main Contributions



This assessment assumed a 100 % correlation between NO<sub>x</sub>-O<sub>3</sub> and NO<sub>x</sub>-CH<sub>4</sub> changes. For 50 % correlation the error bar of Total NO<sub>x</sub> includes negative values.



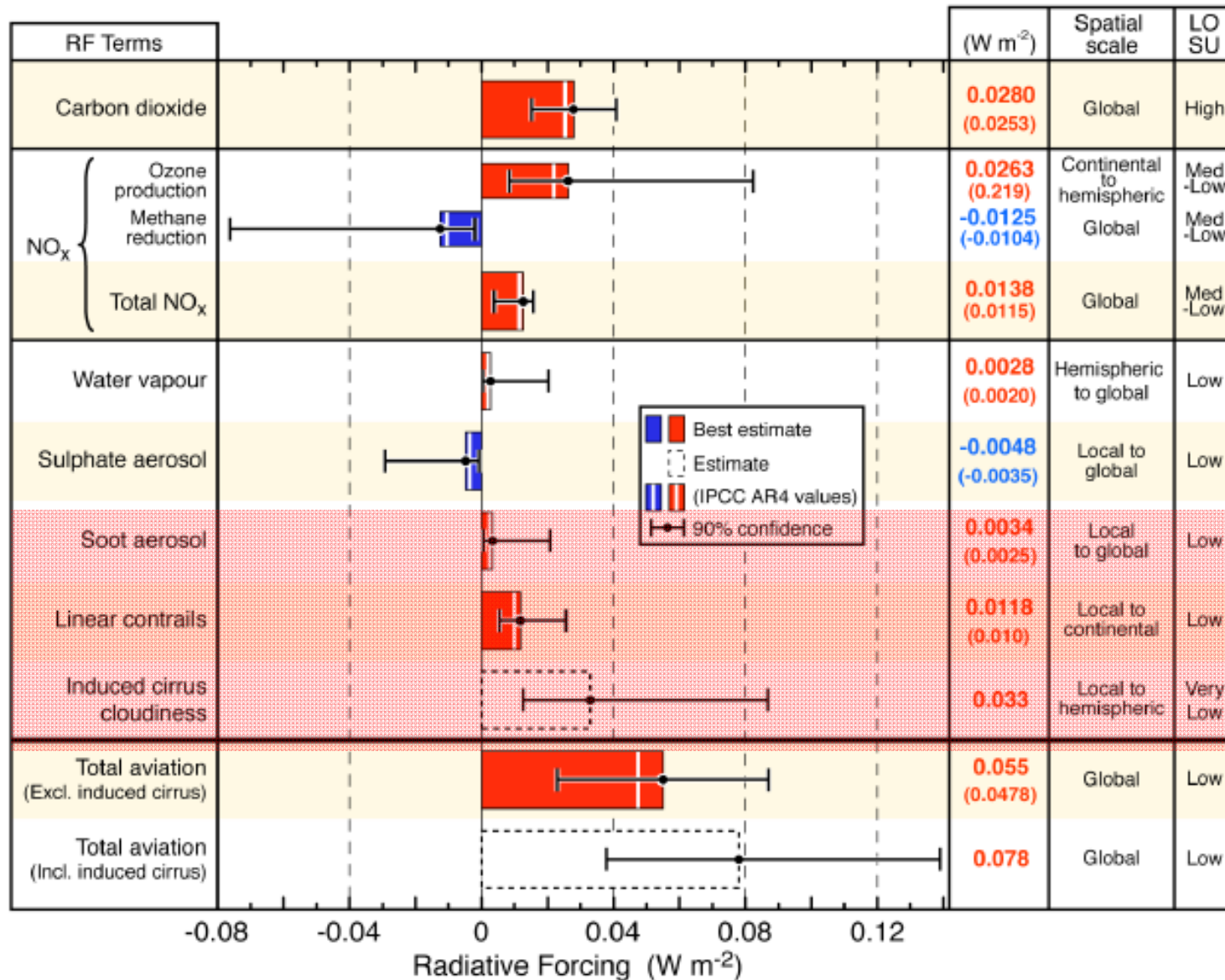
# Aviation Radiative Forcing: Main Contributions



Some recent publications indicate larger methane reduction than assessed here, and hence negative RF-values for total NO<sub>x</sub> cannot be excluded



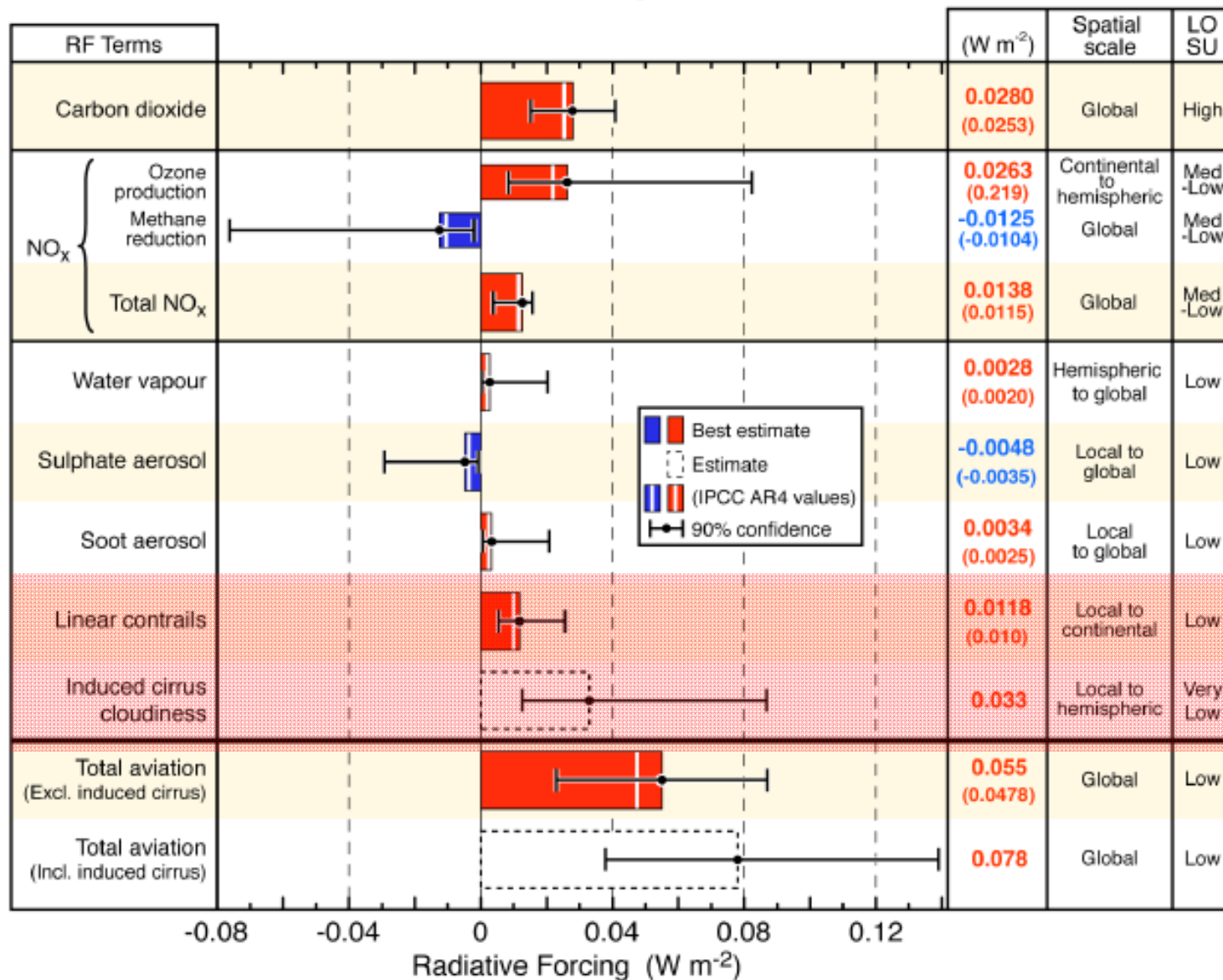
# Aviation Radiative Forcing: Main Contributions



**Induced cirrus cloudiness depends on soot and contrails.**

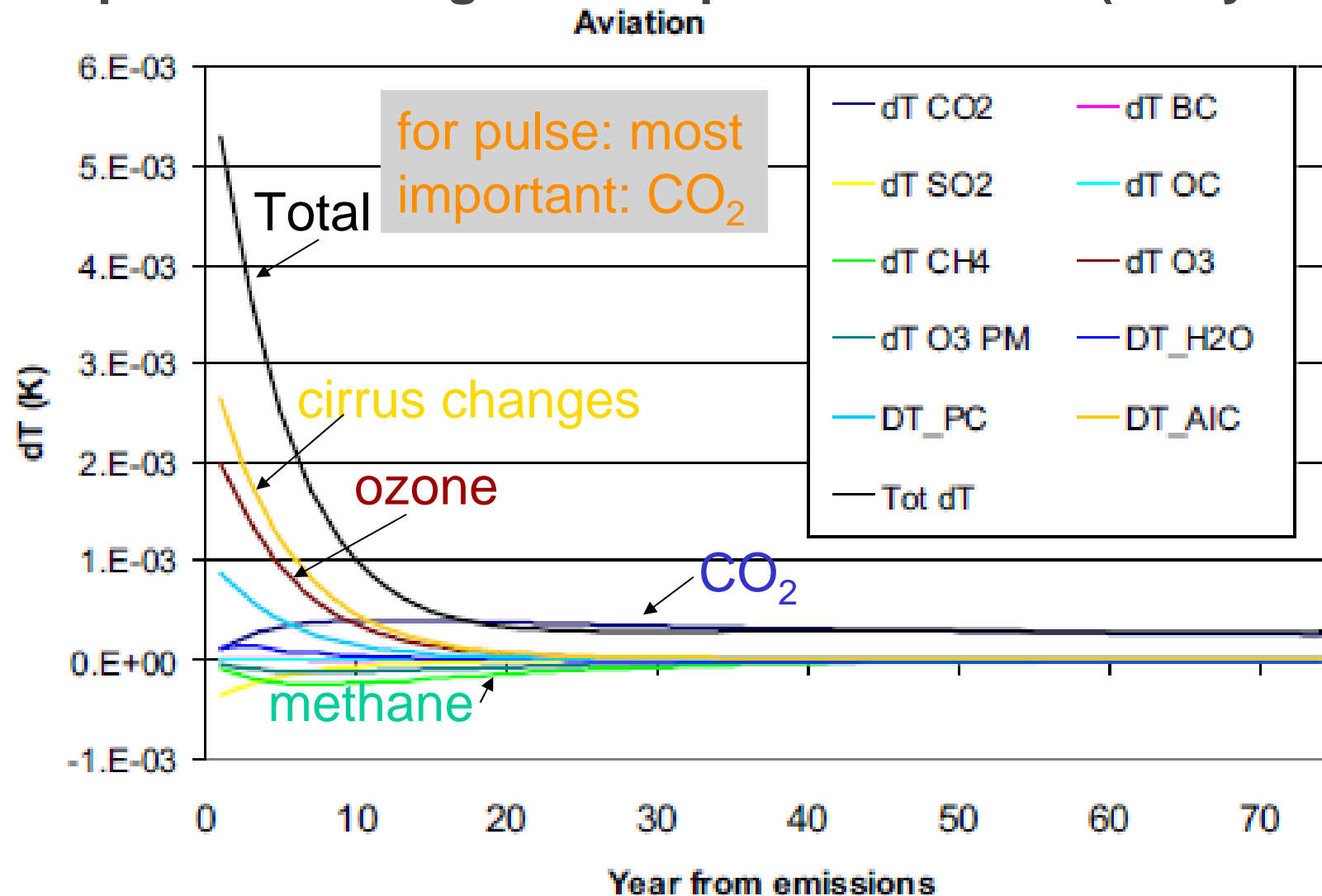
**Outside contrails, soot cause RF<0, inside contrails soot cause RF>0**

# Aviation Radiative Forcing: Main Contributions



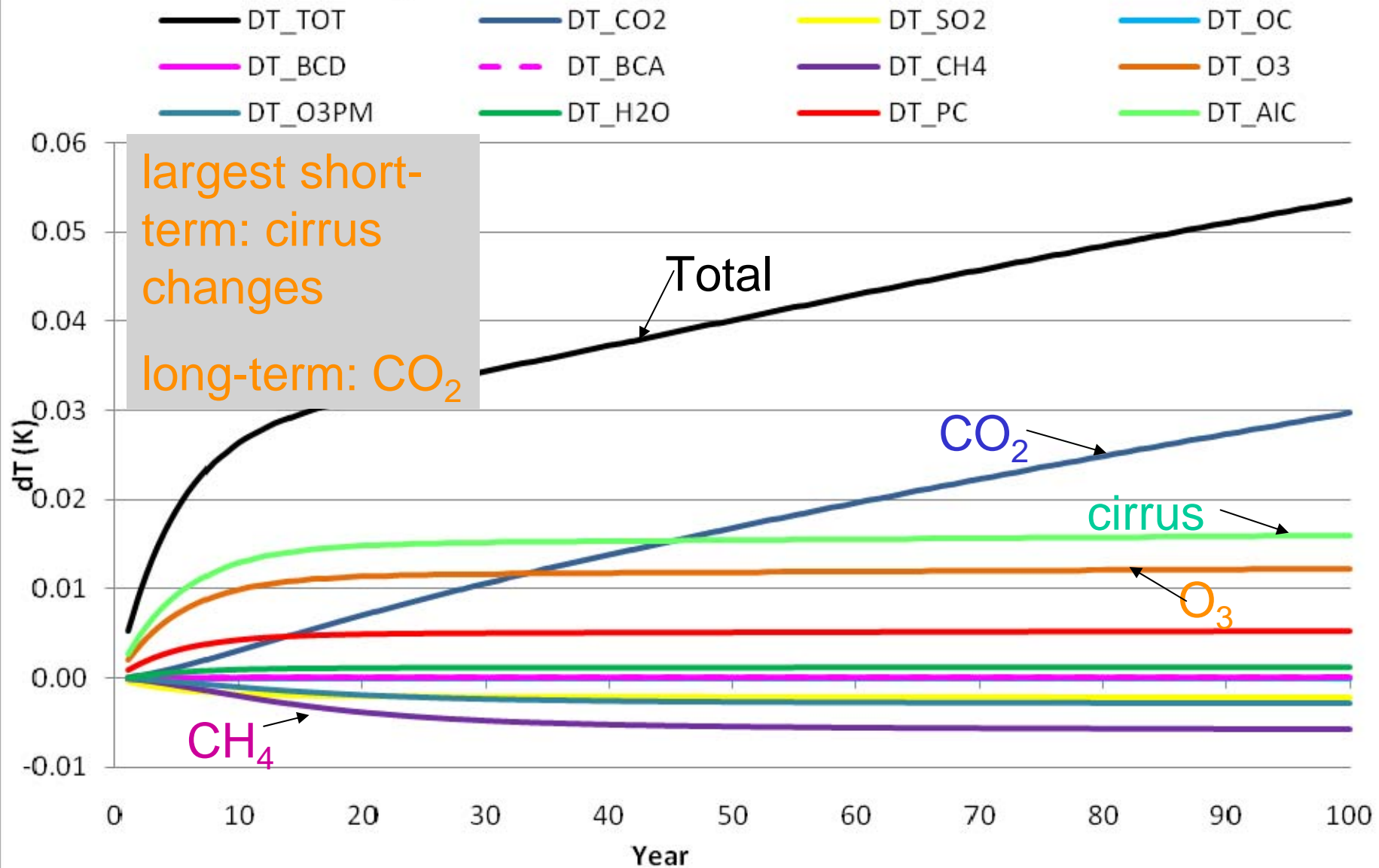
**Recent DLR-studies show that contrail induced cirrus clouds may cause RF >0.1 W m<sup>-2</sup>**

# The climate impact depends on the scenario and time scale: E.g., Temperature change from a pulse emission (one year)



(Berntsen & Fuglestvedt, PNAS, 2008)

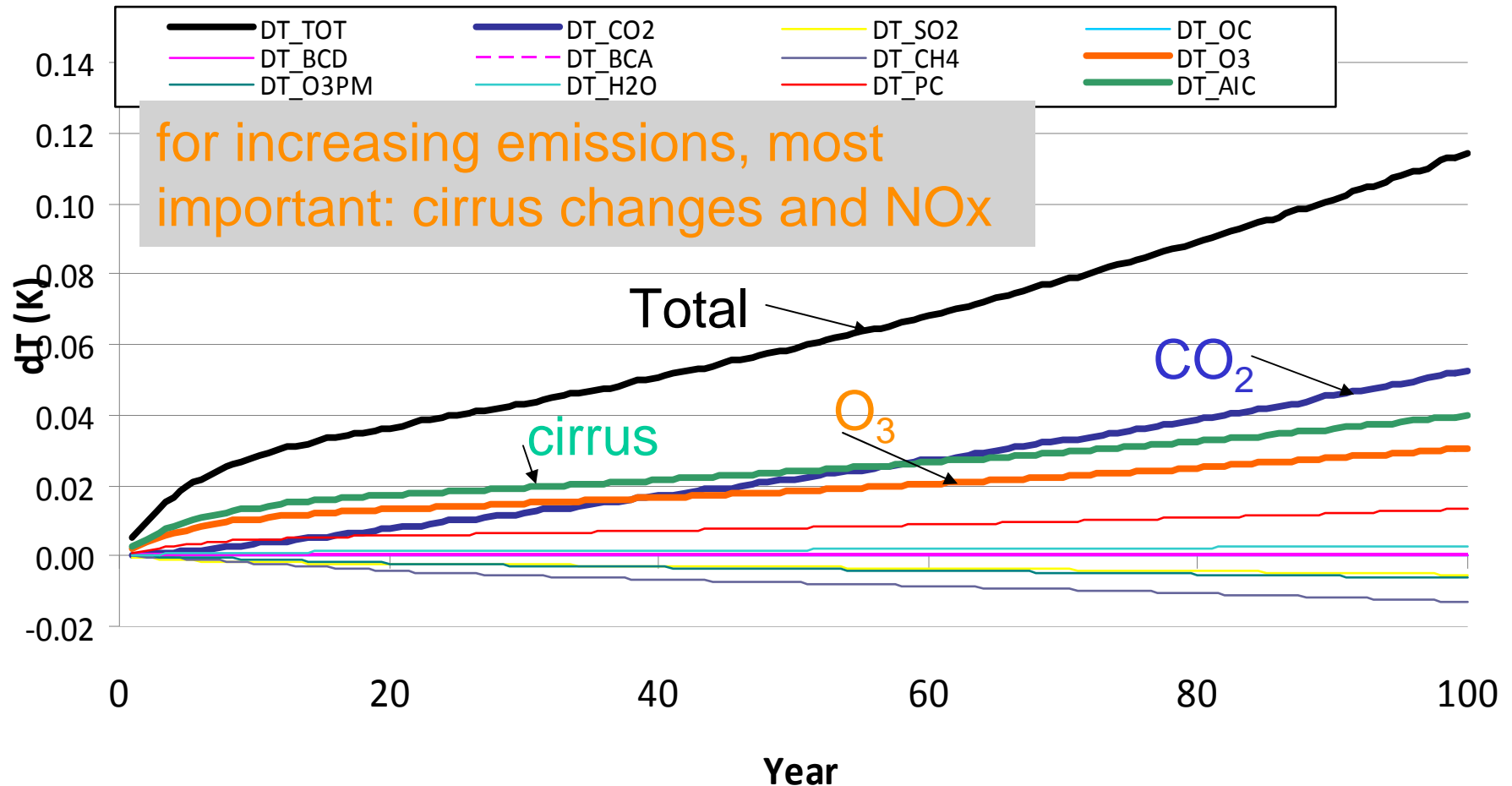
# Temperature change due to sustained emissions from aviation



(Berntsen & Fuglestvedt, PNAS, 2008)

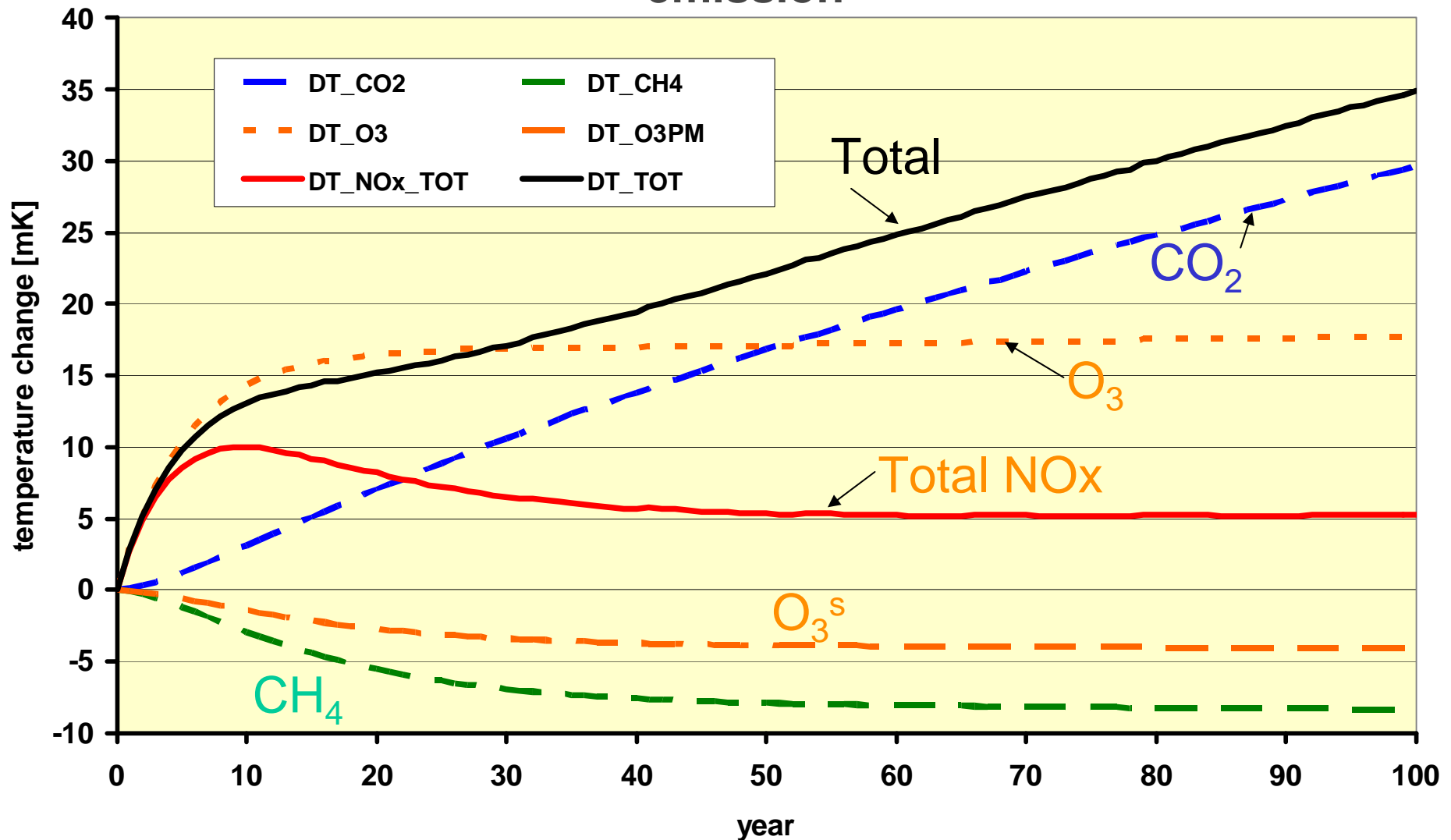


## Temperature increase due to year 2000 plus 1% annual increase in aviation emissions



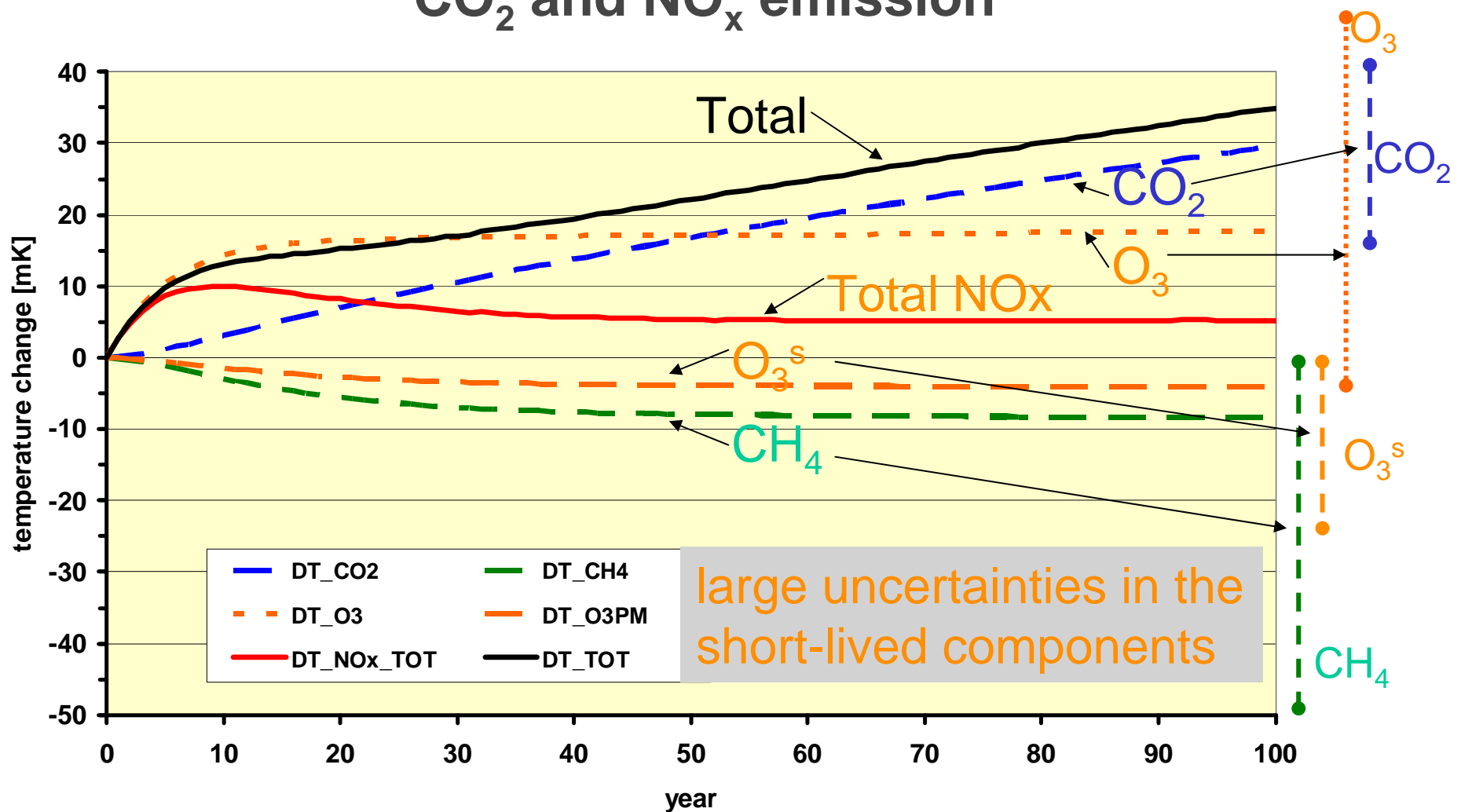
(Fuglestvedt and Lund, pers. communication, 2009)

## Uncertainties: Temperature changes from aircraft CO<sub>2</sub> and NO<sub>x</sub> emission



(Sausen et al., based on Fuglestvedt et al. (2008), pers. communication 2009)

# Uncertainties: Temperature changes from aircraft $\text{CO}_2$ and $\text{NO}_x$ emission



(Sausen et al., based on Fuglestvedt et al. (2008), pers. communication 2009)



# New measurements with DLR Falcon over the North Sea behind A319, A340, A380, B737, CRJ2 aircraft

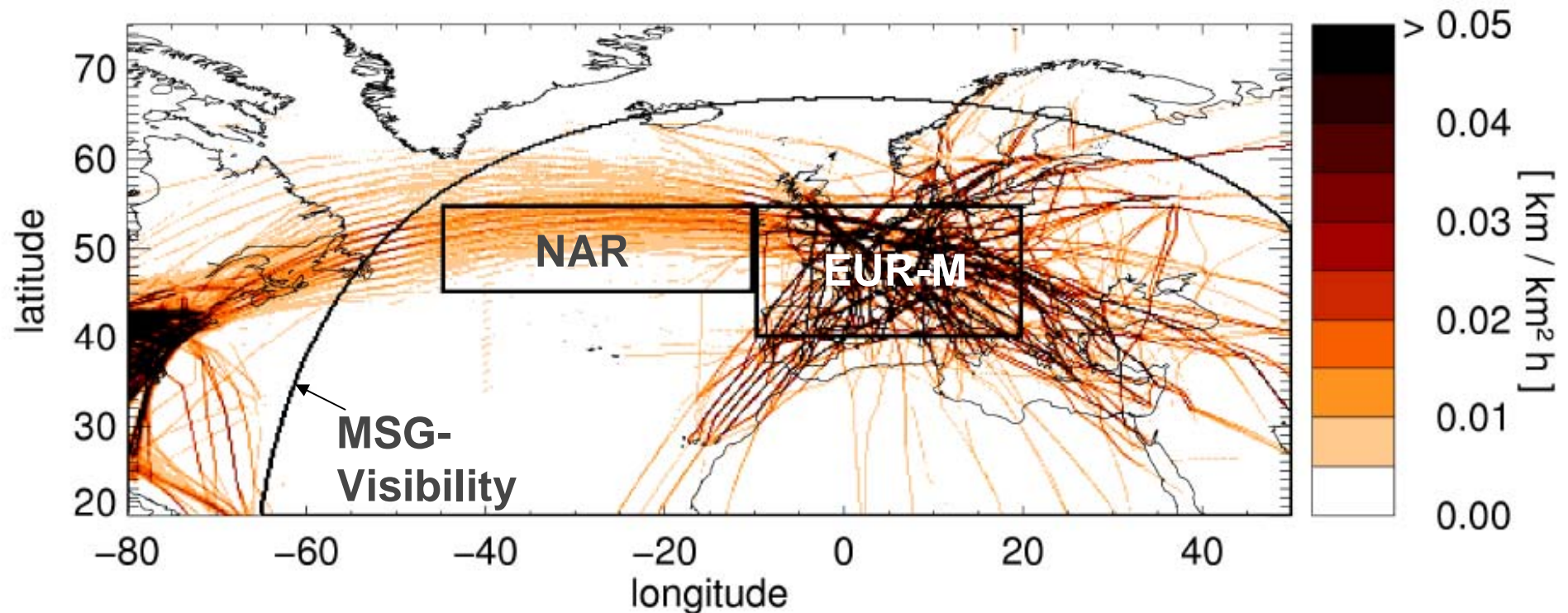


**Result: Contrails of larger aircraft compared to smaller ones are thicker and stay longer**

**More soot causes smaller ice particles which sediment later and cause longer contrails therefore**

# The diurnal Traffic and Cirrus cycles in the North Atlantic Region, NAR, provides an Aviation Fingerprint:

Annual mean Air traffic density (ATD) in  $\text{km}/(\text{km}^2 \text{ h})$

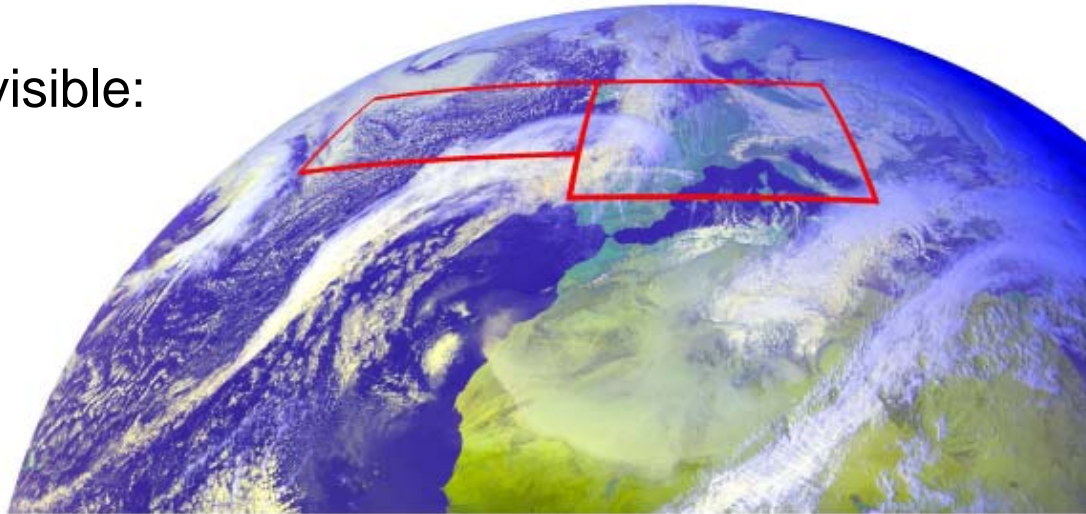


Vertically integrated traffic data above 6 km from  
EUROCONTROL at 15 min time resolution

(Graf, Mayer, Mannstein, Schumann et al., DLR, 2009)

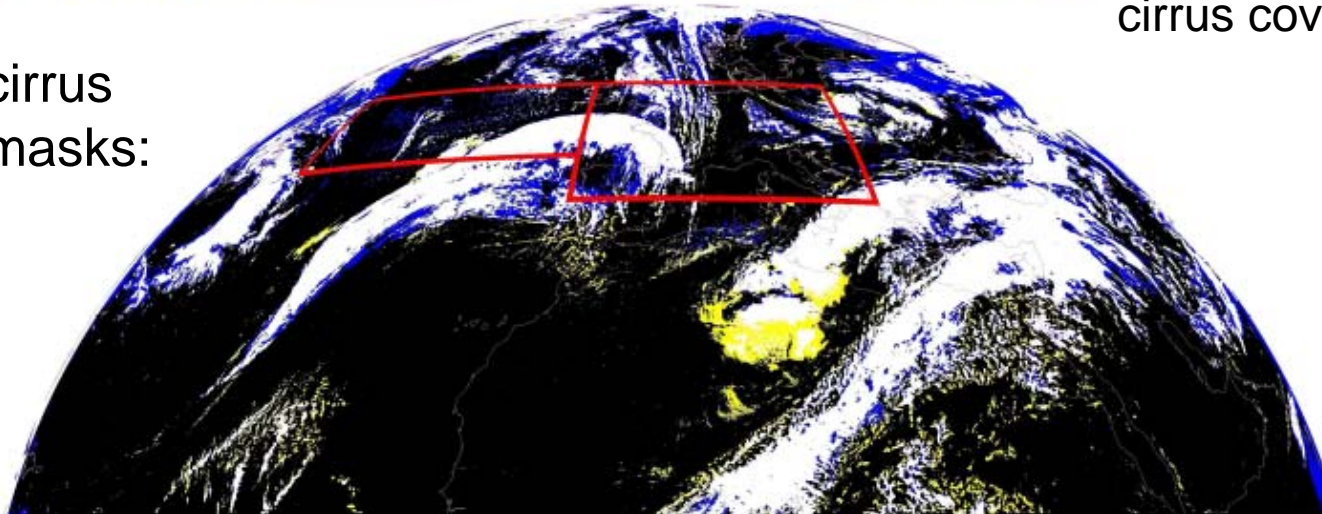
# Cirrus cover determined from a new (day and night time) Meteosat Cirrus detection algorithm: MeCiDa

visible:



- uses 7 IR channels of SEVIRI
- cirrus detection at day and night.
- combines morphological and multi-spectral threshold tests
- detects optically thin ( $> 0.4$ ) ice clouds.
- Data include 4 years of 15 min cirrus cover, Feb 2004–Jan 2008

cirrus masks:



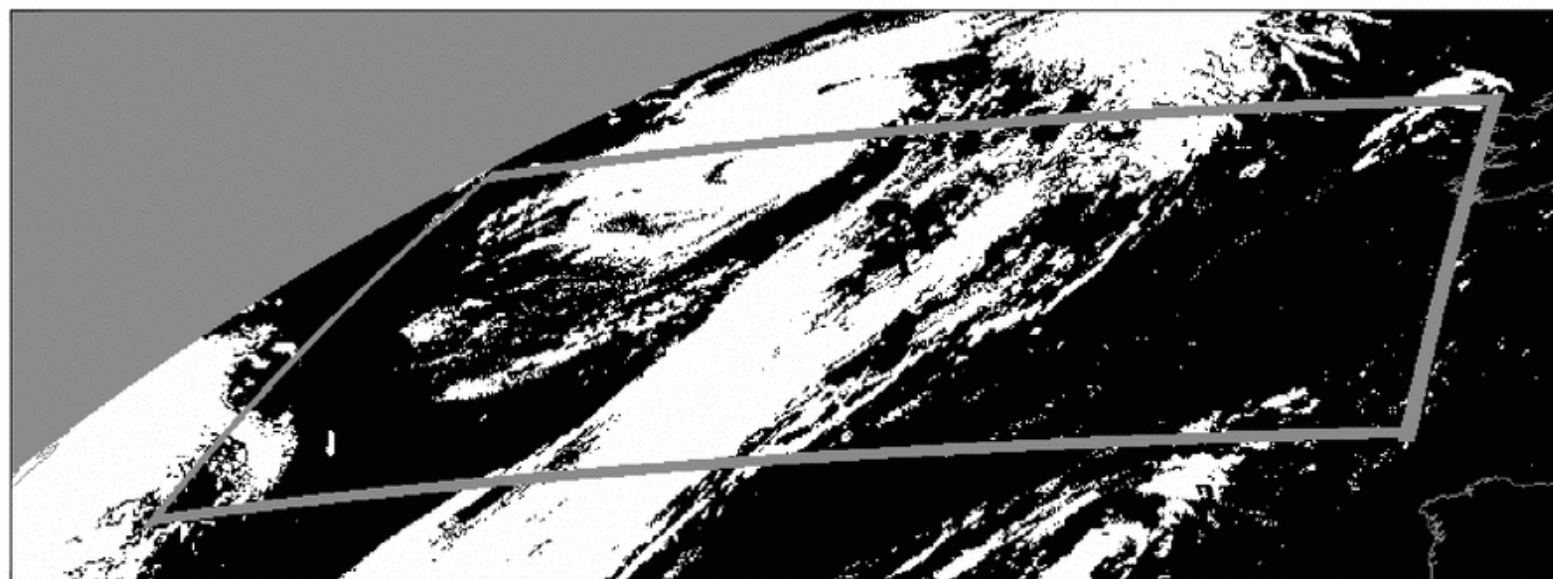
(Krebs, Mayer et al., 2007)



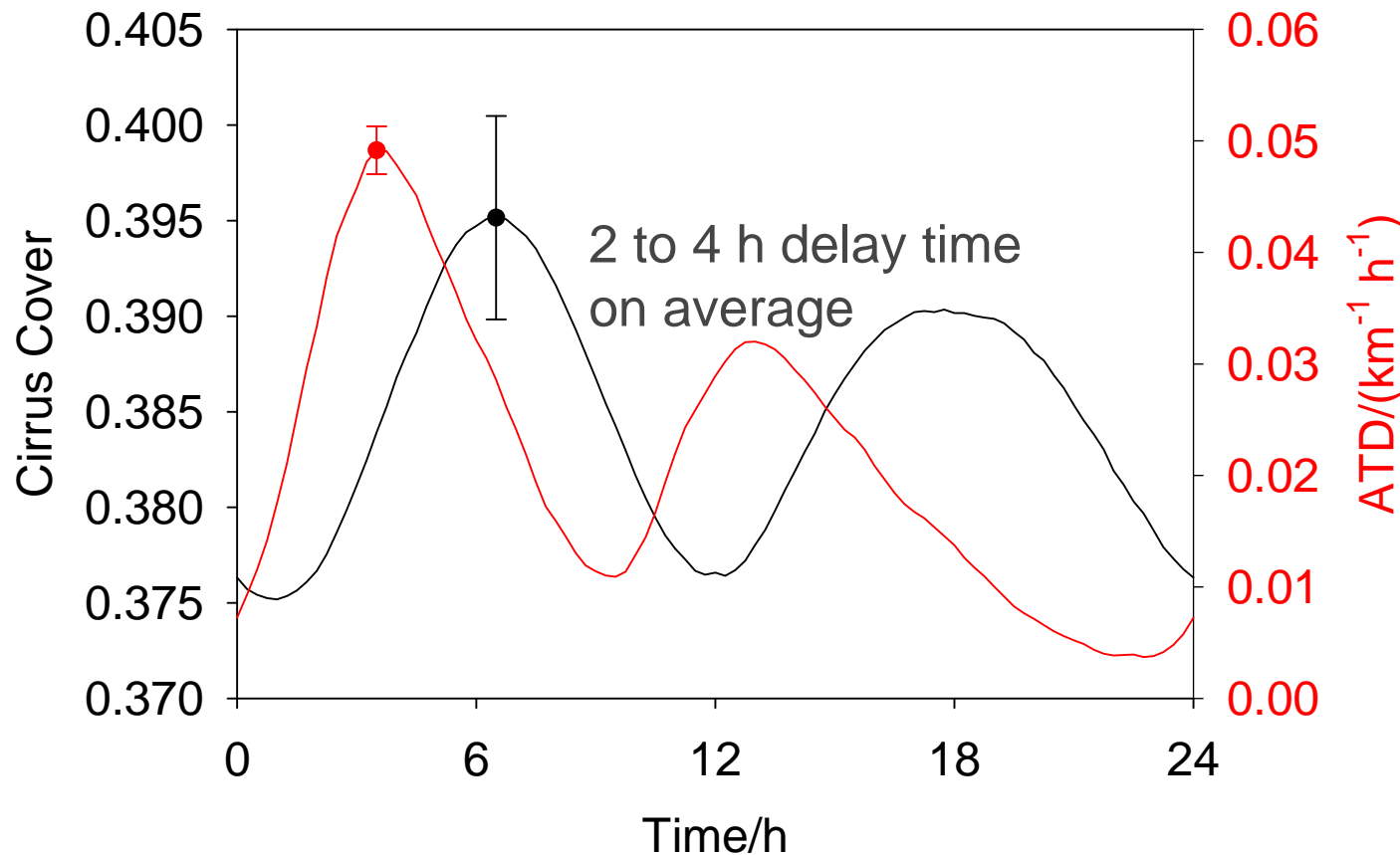
Air traffic density in  $\text{km} / (\text{km}^2 \text{ h})$ , 25.04.2004, 00:00 UTC



MeCiDA cirrus classification, 25.04.2004, 00:00 UTC



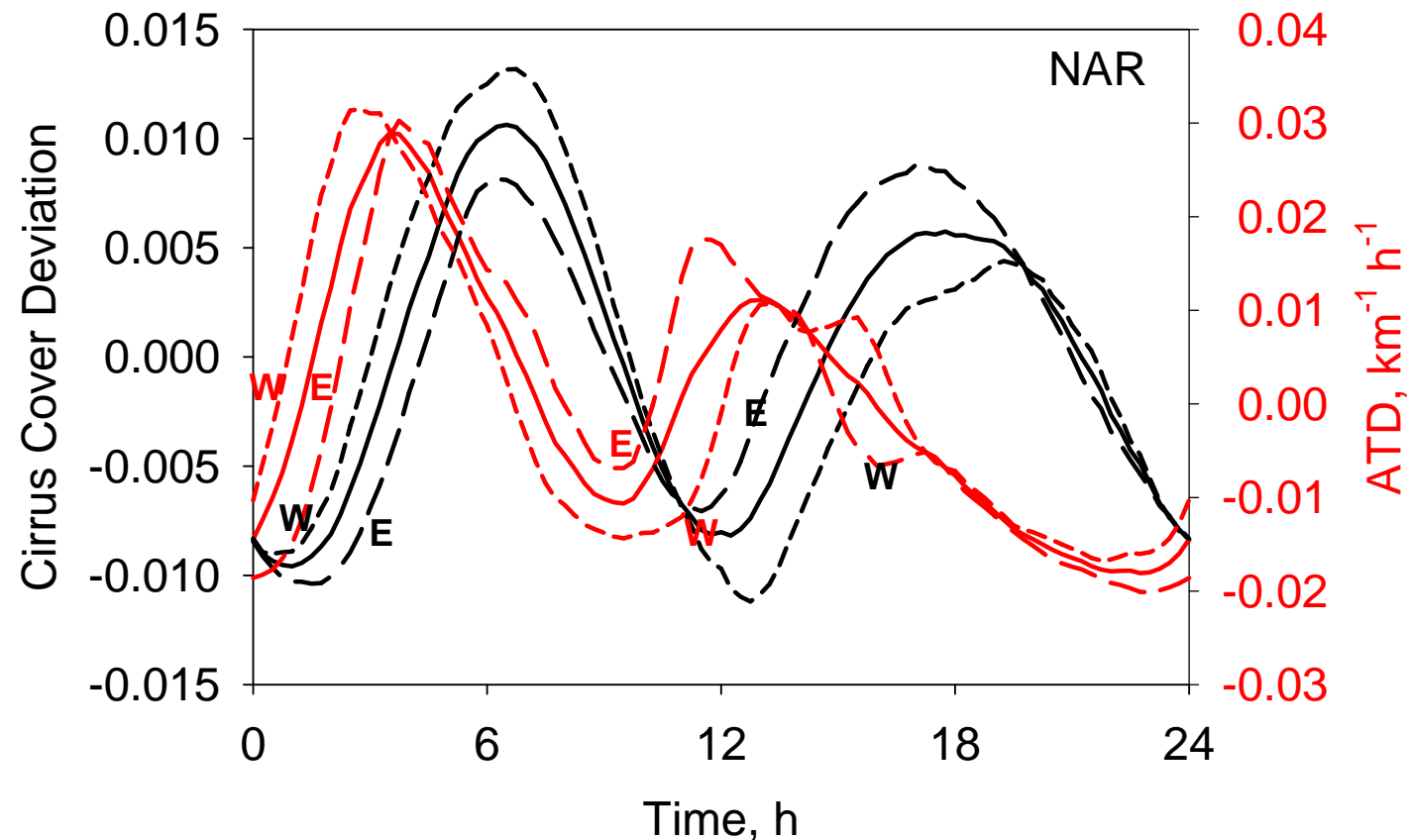
## Annual mean cirrus cover and air traffic density (ATD)



Cirrus cover follows air traffic with 2 to 4 h delay (this is the time to spread contrail cirrus to maximum width and thickness visible for the satellite)

The cirrus amplitude is far larger than expected for line-shaped contrails so far.

**When dividing the NAR into 2 equal 17.5°x10° W-E-subregions: cirrus cover and ATD density are well correlated**



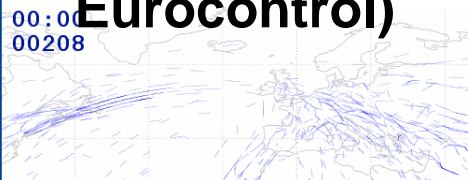
Diurnal traffic and cirrus cycles show correlations in the western and eastern parts separately, which can only be explained by aviation impact on cirrus

# A new DLR-model Contrail Cirrus Simulation and Prediction (CoCiP)

**Input:**  
**Aircraft**  
**(BADA)**



**Movements**  
**(ATM data, DFS,**  
**Eurocontrol)**

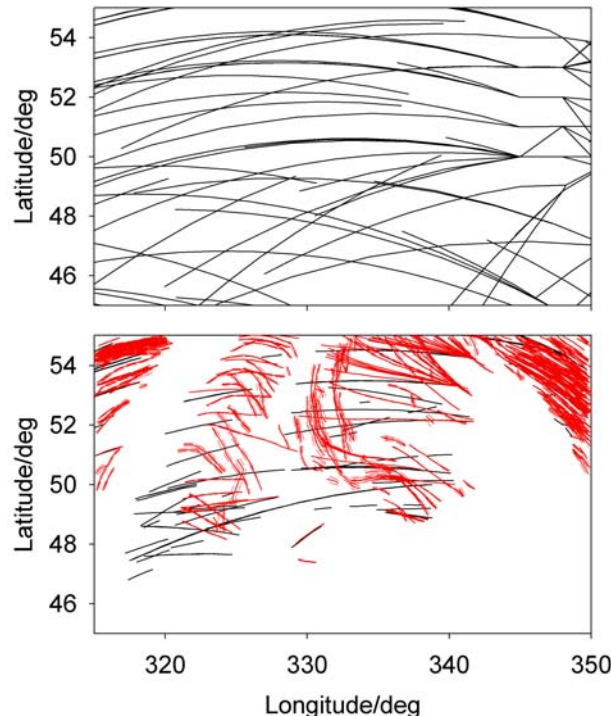


**Meteorology**  
**(NWP results,**  
**ECMWF, DWD)**



## Contrail Cirrus Prediction Tool

NAR, 12. Aug 2005, 3-6 UTC



- From regional to global
- Comparable to observations

**Output:**  
**Contrail,**  
**life cycle,**  
**cover, radiation**

**Cirrus**  
**Simulation**  
**(insitu, Lidar,**  
**Satellite)**

**Sensitivity**  
**studies**

**Prediction**  
**Climate impact**

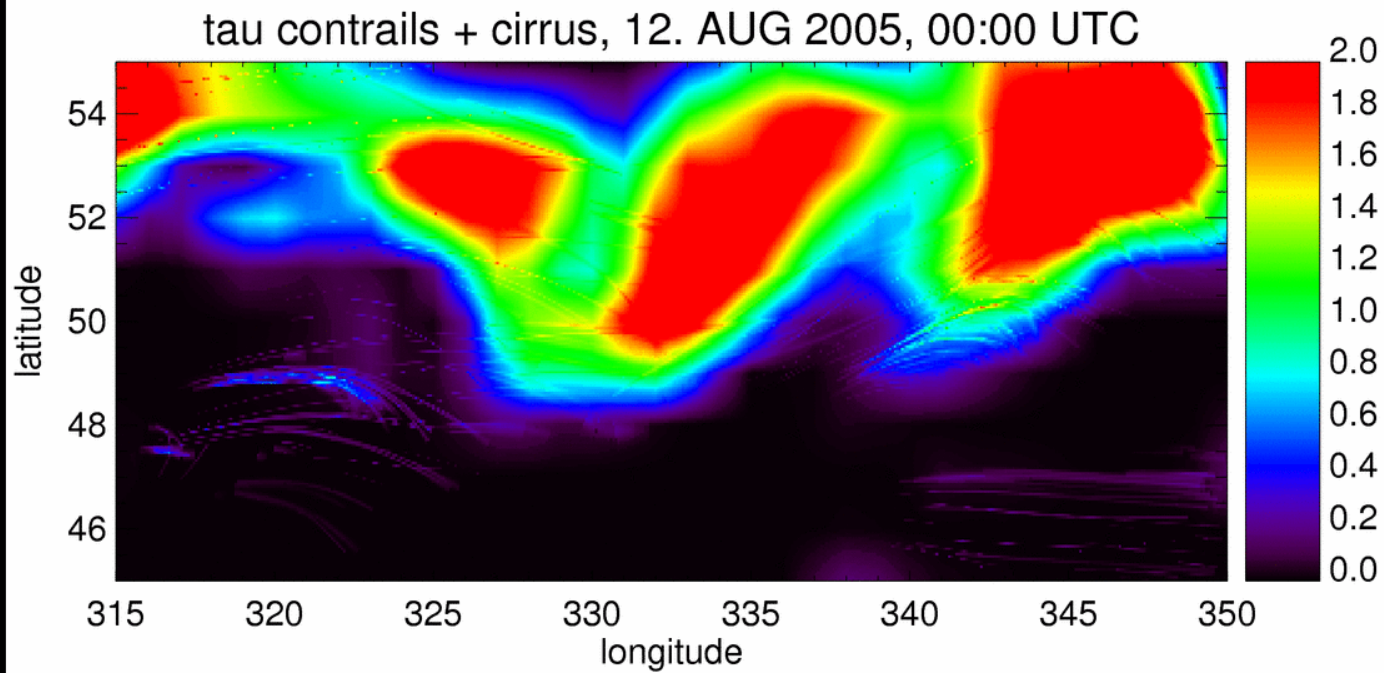


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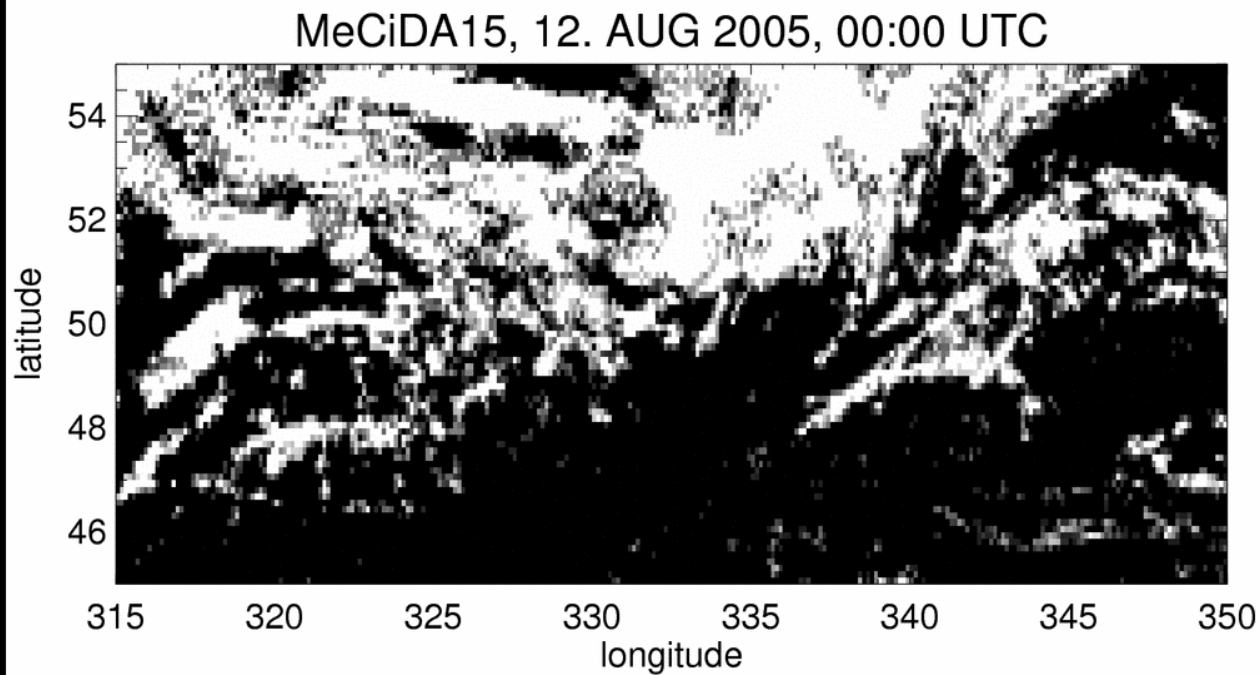
DLR-Institut für Physik der Atmosphäre und MIM/LMU München

(Schumann, 2009)

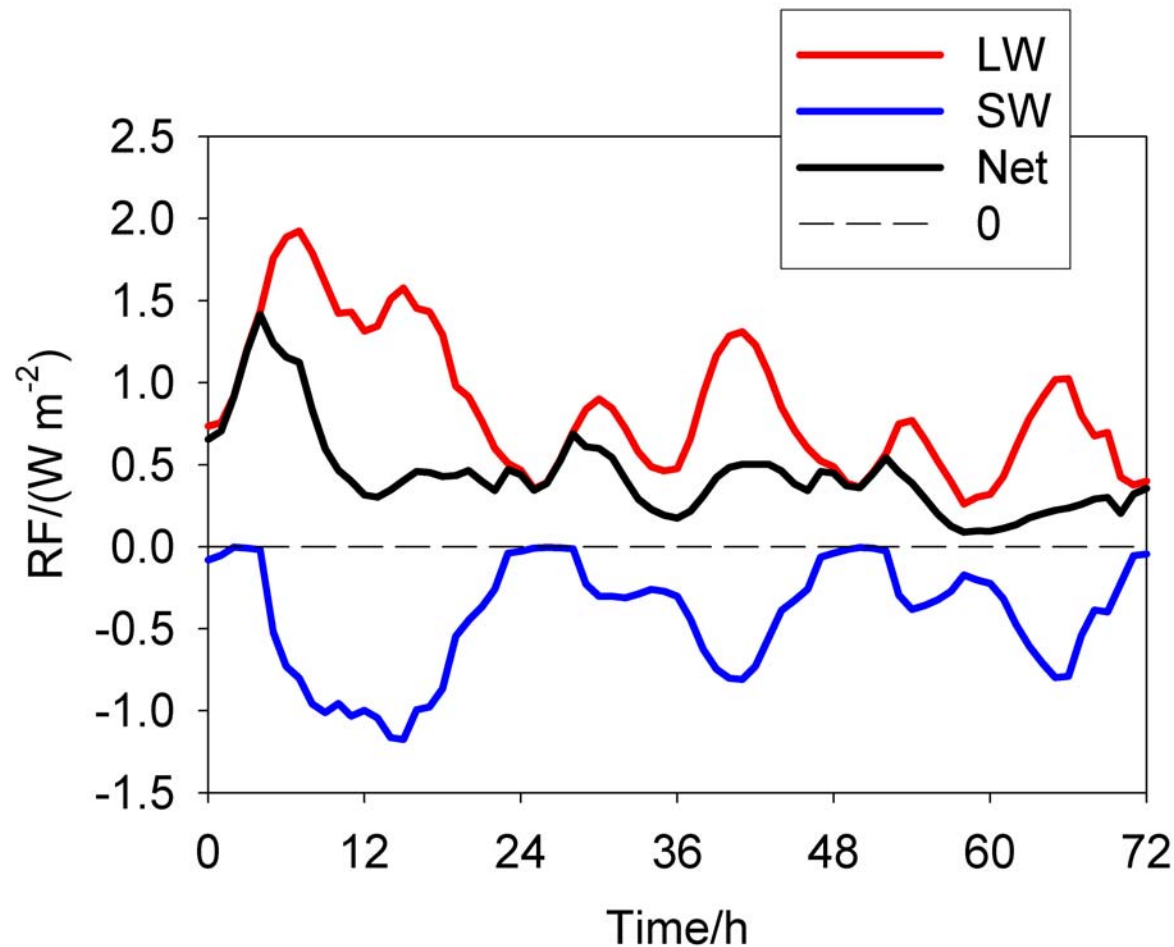




**Modeled cloud  
thickness (tau)  
(top) show  
structures  
comparable to  
observations  
(bottom)**



## Regional radiative forcing for NAR reference case



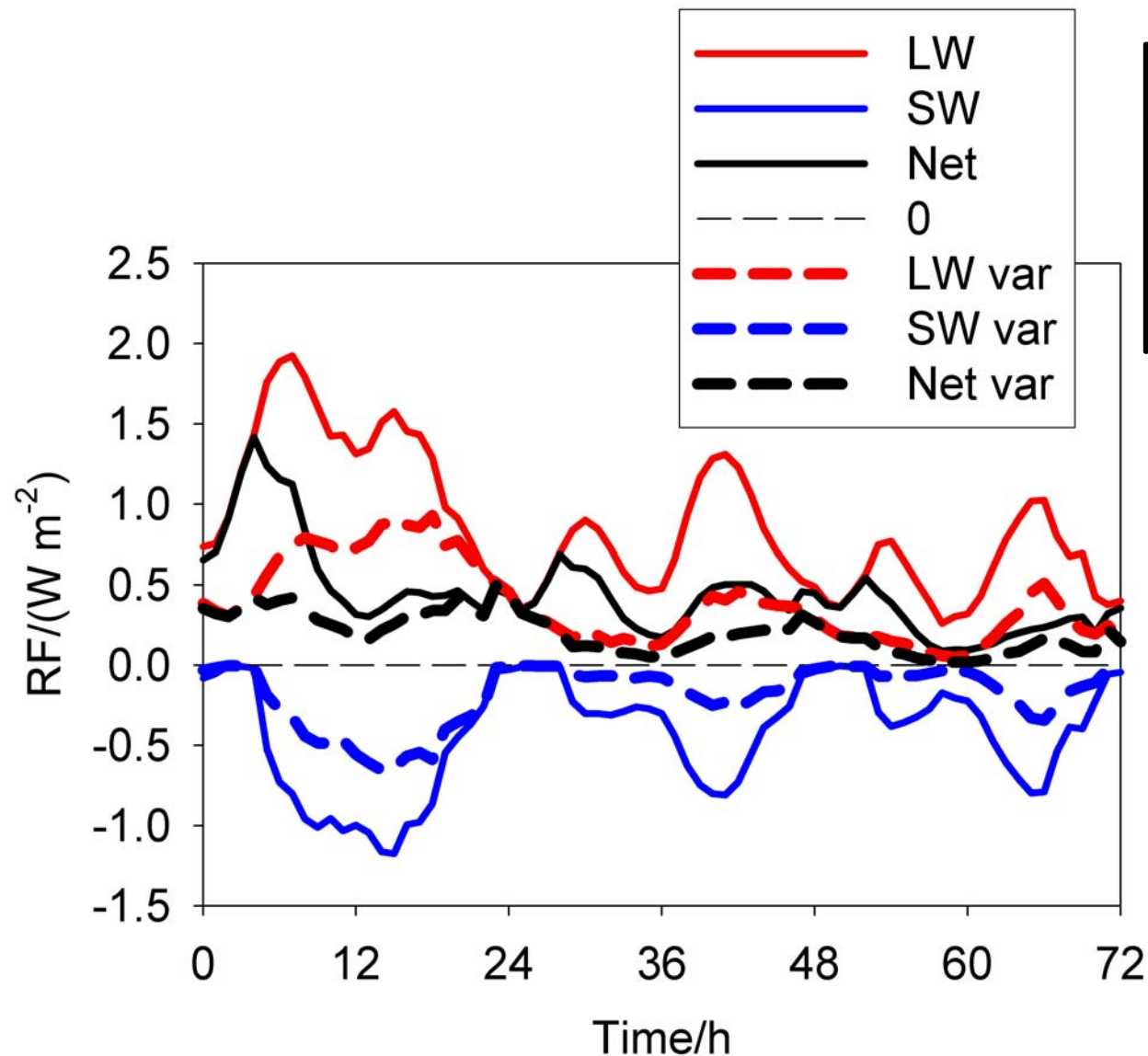
[W/m <sup>2</sup> ]	
LW	0.86
SW	-0.42
Net	0.44

all day LW  
warming

daytime SW  
cooling

all day net  
warming in  
this case

## Flying 600 m higher or lower, minimizing contrails



[W/m <sup>2</sup> ]	fix	var.
LW	0.86	0.38
SW	-0.42	-0.18
Net	0.44	0.20

**by adjusting flight levels to minimum humidity, more than 50 % of the contrail heating effect can be avoided**

# Conclusions

- Global traffic climate impact: aviation is second after road
- The CO<sub>2</sub> impact remains for centuries. Requires non-fossil fuels.
- The NO<sub>x</sub> impact is less important than thought when formulating ACARE objectives in 2000. NO<sub>x</sub> may even cause long-term cooling though warming dominates for increasing emissions.
- The climate impact of contrail cirrus is larger than estimated so far.
- Contrail cirrus can be reduced by flying higher or lower, depending on the predicted weather situation; this pays even for small increases in CO<sub>2</sub>.
- A reduction of soot emissions helps to reduce the climate impact of contrail cirrus.
- In addition, soot changes cirrus outside contrails, causing cooling.
- Limiting global warming to less than 2°C requires quick actions on all warming contributions, including CO<sub>2</sub>, but also all short-lived effects (NO<sub>x</sub>, contrails and soot)